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A model of aircraft life cycle cost ~~is developed~~. ~~This cost is~~ estimated to be a function of the production schedule. The effect modeled is the cost variation as a function of increasing aircraft reliability achieved after the completion of a number of operating hours. An optimization problem is outlined that yields the best production schedule. A search algorithm for this difficult integer nonlinear programming problem

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20. Abstract (cont'd)

is used to find the optimum schedule. Present practices with advanced jet aircraft are found to be suboptimal in several respects. Recommendations include a linear production buildup that continues much longer than at present and extension of the development phase of an aircraft program well beyond the current termination time.

AIRCRAFT PRODUCTION AND DEVELOPMENT SCHEDULES

by

Robert A. Harrison

Serial T-463
15 April 1982

The George Washington University
School of Engineering and Applied Science
Institute for Management Science and Engineering

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TABLE OF CONTENTS

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AIRCRAFT PRODUCTION AND DEVELOPMENT SCHEDULES

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1. Introduction

Under the Duane model of reliability growth of aerospace components, the failure rate of a component under development is inversely proportional to the number of operating hours raised to a power that Duane estimated to be approximately one-half [3]. Thus, the life cycle cost of an aircraft declines as the aircraft program progresses, not only because production costs decline, but because operating and support costs decline. The improvement continues until the design is frozen on termination of the Test, Analyze, and Fix (TAF) phase.

If this hypothesis is coupled with a predicted operating schedule and a predicted value of the Duane curve exponent, an expected life cycle cost can be determined for each aircraft for any given production schedule. Each possible schedule has an associated program cost, and the production schedule selected should be the one meeting the program requirements that has the lowest cost.

Selection of the schedule may be regarded as the optimization of a vector in n-dimensional space, where n is the number of aircraft lots and the sum of the n ordinates must equal the total number of aircraft

required. The optimum vector minimizes the sum of six subcosts, (1) non-recurring investment, (2) manufacturing, (3) recurring investment, (4) TAF cost, (5) operation and support, and (6) modification. Each subcost has a minimizing vector, such as the vector of equal ordinates, which minimizes non-recurring investment. The minimizing subcost vectors are the basis of a subspace that contains the unknown optimum vector.

Predictable reliability improvement makes possible the optimization of the duration of the TAF phase in addition to the optimization of the production schedule. TAF brings reductions of operating costs that are very high initially and decline as production continues. The reduced operating costs are bought at the expense of TAF engineering, retooling, and the cost of modification of aircraft produced previously. The ideal TAF effort would end just at the point at which the expected reduction in operating costs no longer would pay the TAF costs. The optimizing vector has $n + 1$ dimensions, n for the production schedule and one for the TAF phase duration.

Such an optimization has been made for a class of aircraft considered amenable to the optimization because of its reliability improvement characteristics - the first generation, high performance, jet fighter. The inputs for the analysis were a reliability model and a cost model described in Sections 2 and 3 respectively. The analysis itself is described in Section 4.

Conclusions are presented in Section 5. The basic conclusion is that a similar analysis should be made for every new aircraft program with appropriate potential reliability improvement. Recommendations include a linear production build-up, a gradual production build-up that continues much longer than it does at present, and extension of the TAF phase of an aircraft program well beyond the current termination time for certain aircraft.

2. Reliability Model

Basic Reliability Equations. Two equations were used for the prediction of the reliability of a lot of a first generation aircraft:

$$U_i = F_a \left[1-(1-c)\ (k_{13} \cdot w_{3,i-1})^{-c}\right]$$

$$P_i = F_p \left[1-(1-c)\ (k_{13} \cdot v \cdot w_{3,i-1})^{-c}\right]$$

where

U_i = failures per flight hour, avionics plus airframe, lot i

F_a = failures per flight hour, avionics plus airframe, first aircraft

c = Duane Curve Exponent

k_{13} = flight hours per aircraft per three-month period (80 in this study)

$w_{3,j}$ = total periods flown in all aircraft in the program by end of period j

P_i = failures per flight hour, propulsion system, lot i

F_p = failures per flight hour, propulsion system, first aircraft

v = number of engines in aircraft

The Duane Relationship thus was the basis of the reliability predictions. The relationship was selected after a study of all Air Force aircraft covered in AFALD Pamphlet 800-4 [11], all Navy aircraft in the Aircraft Maintenance Experience Design Handbook [5], and one Army aircraft, BLACKHAWK.

This study revealed no aircraft except first generation aircraft that exhibited statistically significant reliability improvement. However, all first generation aircraft showed highly significant improvement in accordance with the Duane Relationship except for three aircraft in special categories. Furthermore, the deviation from the fitted Duane Equation was very low in every case. Figure 1 shows a typical example, the F-15A reliability improvement.

Considerable variation was shown, however, in the fitted value of c. Only one aircraft had a value equal to or greater than the original Duane estimate of .5 for aerospace subsystems in general. BLACKHAWK, which had a production phase failure curve exponent of .652 and a production phase removal curve exponent of .499, was rejected as an outlier because the flight hours totaled less than 5,000. All other aircraft had exponents in the .1 - .3 range. As a consequence, .2 and .05 were selected as the predicted value of c and the standard error of the estimate, respectively. The improvement curve realized in a program may depend to a considerable extent upon the emphasis on reliability rather than the inherent aircraft characteristics.

Prediction of flight periods. Flight periods were predicted to remain at their present levels since there was no reason to expect any change in the present attrition, rework, or operating lifetime averages. The estimated current averages for high performance Navy fighters were an attrition rate of .95 per year, a rework every 3.5 years, and retirement after the third rework cycle. Rework was expected to require six months, with all reliability and maintainability modifications being effected during reworks.

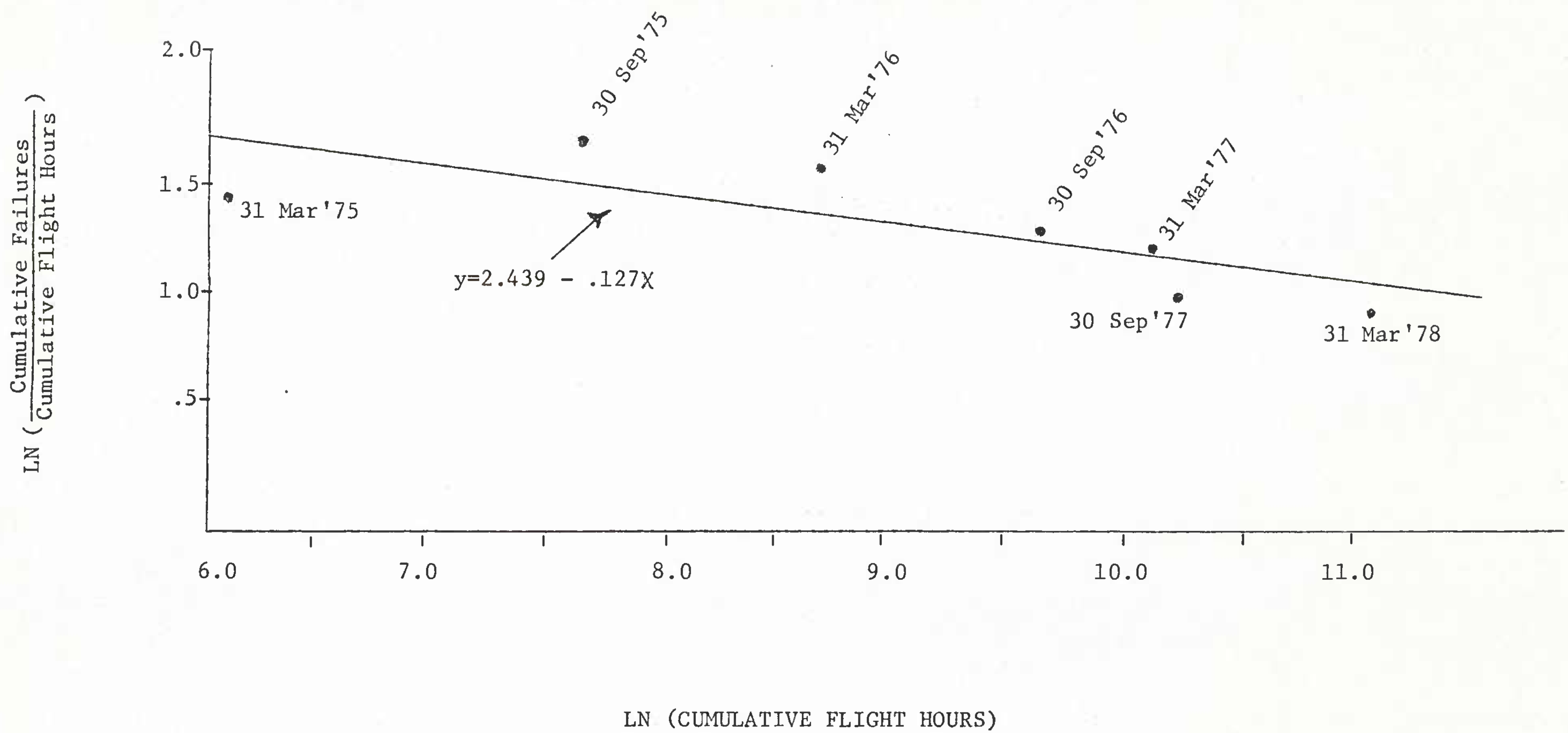

Figure 1. The F-15A, an Example of Reliability Improvement

The expected number of three-month flight periods for an aircraft thus was $1 + a + a^2r \ldots + a^{55} = \frac{1-a^{56}}{1-a} = 40.21$, where a = three-month attrition rate, $.95^{.25}$. The number of aircraft in service during period n , $s(n)$, was given by

$$s(n) = \sum_{i=n-1}^{n-14} X_i(a)^{n-i-1} + \sum_{i=n-17}^{n-30} X_i(a)^{n-i-3} + \sum_{i-n-33}^{n-46} X_i(a)^{n-1-5} + \sum_{i=n=49}^{n-62} X_i(a)^{n-i-7}$$

where

X_i = number of aircraft produced in period i ,

$X_i = 0$ when $i < 1$.

The number of periods flown in all aircraft in the program by the end of period j , $w_{3,j}$, was given by

$$w_{3,j} = \sum_{n=1}^{j} s(n) .$$

Utilization. A utilization of 80 flight hours per quarter per operating aircraft was predicted. This prediction was considered more realistic than a prediction of a peacetime utilization of 105 hours per quarter because 80 hours is what has actually been achieved in the past rather than what is desired for the future.

3. Cost Model

The life cycle cost model included only costs considered to vary with the production schedule, the duration of the test, analyze and fix (TAF) period or both. The relevant life cycle costs were divided into six subcosts: (1) non-recurring investment, (2) manufacturing, (3) recurring investment, (4) TAF cost, (5) operation and support, and (6) modification. All costs were undiscounted and were in 1975 dollars.

Non-recurring investment. The non-recurring investment cost, f_1, was estimated by

$$f_1 = k_{11} \, k_4 \, (y_0)^{e2}$$

where

k_{11} = coefficient of estimate of tooling provision hours = 700,000

k_4 = cost of tooling provision hour = \$25

y_0 = peak production rate of aircraft program, aircraft per month

$e2$ = exponent of estimate of tooling provision hours = .4 .

The values of k_{11} and $e2$ were based on figures for the F89, F100, F101, and F105 given in Levenson and Barro [7]. The estimated value of $e2$ was considered to be open to question because previous studies have indicated lower values, including a value of zero, which was used in Boren [1]. However, use of a value of zero did not change any relative production schedule preferences significantly, so the uncertainty was not considered to be important. The hourly cost estimate was based upon Boren [1].

Manufacturing cost. The manufacturing cost, f_2, was estimated by

$$f_2 = \sum_{i=1}^{n} \left[x_i^{e3} \, L \sum_{j=1+y_{i-1}}^{y_i} j^{e4} \right] + \sum_{i=1}^{n} \left[x_i^{e3} \, M \sum_{j=1+y_{i-1}}^{y_i} j^{e6} \right]$$

where

n = number of three-month manufacturing periods = 40

X_i = number of aircraft manufactured in period i

L = labor portion of flyaway cost of first aircraft = $24,500,000

$e3$ = cost exponent of production lot size = - .08

$y_i = \sum_{j=1}^{i} X_j$ = cumulative aircraft produced through period i

$e4$ = labor cost learning curve exponent = - .415

M = materials portion of flyaway cost of first aircraft = $3,300,000

$e6$ = materials cost learning curve exponent = - .07

Values of L and M were based on regression analyses of high performance jet fighter aircraft and were intended to be typical of the prototype costs to be encountered in the last two decades of this century. The value of e3, which happened to be the same for both labor and materials, was based on records for the A-7, F-4, F-102, and KC-135 given in Dreyfuss [2]. The selection of ten years for the production period was based primarily upon the expected duration of technological non-obsolescence, a soft tooling life of at least three years at prototype production rates, and a hard tooling life of seven years at the very least at an average production rate of approximately twelve per month.

The value for e4, which yields a 75 percent learning curve, was based principally upon Scott [9]. The materials cost exponent, which yields a 95 percent learning curve, seemed reasonable on the basis of evidence in Dreyfuss, who broke the exponent into two components, - .037 for the model and - .057 for the aircraft.

Recurring investment. The sustaining cost, f_3, was estimated by

$$f_3 = \sum_{i=1}^{n} \left[k_4 \cdot k_{11} \cdot \left(\frac{X_i}{3}\right)^{e2} \left[(y_i)^{.14} - (y_{i-1})^{.14} \right] \right].$$

The sustaining tooling provision hours, like the initial tooling provision hours, were considered to be a function of production rate, and were estimated to be related to the rate by the term $700{,}000 \left(\frac{X_i}{3}\right)^{.4}$. This term was multiplied by the cumulative production term, $\left[(y_i)^{.14} - (y_{i-1})^{.14}\right]$, making the cost a function of the aircraft produced at the rate in addition to the rate itself. This estimation equation was in accordance with Levenson and Barro [7].

Test, Analyze, and Fix Cost. The TAF cost, f_4, was estimated by

$$f_4 = k_{12} g$$

$$- \sum_{i=2}^{g-1} \left[u_i k_{14}(AL+EL) + v_i k_{14}(PL) \right] \sum_{j=i+1}^{n} (X_j)^{e3} \sum_{k=y_{j-1}+1}^{y_i} (k)^{e4}$$

$$+ \sum_{i=2}^{g-1} \left[u_i k_{14}(AL+EL) + v_i k_{14}(PL) \right] \sum_{j=i+1}^{n} (X_j)^{e3} \sum_{k=1+y_{j-1}-y_i}^{y_j - y_i} (k)^{e4}$$

where

$$u_2 = 1-(1-c)\ (k_{13}z_1)^{-c}$$

$$v_2 = 1-(1-c)\ (vk_{13}z_1)^{-c}$$

$$u_i = (1-c)\ [(k_{13}z_{i-2})^{-c} - (k_{13}z_{i-1})^{-c}]\ ,\ i > 2$$

$$v_i = (1-c)\ [(vk_{13}z_{i-2})^{-c} - (vk_{13}z_{i-1})^{-c}]\ ,\ i > 2$$

k_{12} = quarterly reliability and maintainability engineering and engineering support cost = \$500,000 (best case) to \$2,300,000 (worst case)

g = duration of TAF program in quarterly periods

u_i = percentage decrease in failure rate for airframe and avionics, period i

AL+EL = airframe and avionics portions of labor cost, L, = \$19,500,000

v_i = percentage decrease in failure rate for propulsion system, period i

PL = propulsion system portion of L = \$5,000,000

k_{14} = Frager Plan Coefficient - ratio of percentage change in assembly procedures changed as a result of reliability design changes to percentage decrease in failure rate = .1

c = Duane Curve Exponent = .1 (worst case) to .3 (best case)

The estimate of k_{12} was subject to serious uncertainty. The requirement for TAF reliability and maintainability engineers certainly would fluctuate widely, probably decreasing as the program progressed. However, existing records are difficult to use to relate the total TAF engineering hours to the phase of the TAF program. The records also are unsatisfactory for the estimation of R&M TAF engineering hours as a percentage of total TAF engineering hours.

A rule-of-thumb procedure therefore was adopted. The average quarterly engineering cost was estimated rather than the cost for each quarter. In addition, R&M engineering was estimated to average 30 percent of all TAF engineering. An engineering hour with overhead was estimated to cost $25.00 by itself and to require two support staff hours at a total additional cost with overhead of another $25.00.

The result was a k_{12} estimate of $1,300,000. Because of the uncertainty, however, sensitivity was examined at the extreme estimates of $500,000 and $2,300,000. This examination indicated that the study conclusions would hold throughout the range.

The last two terms of f_4 represented the increase in the production labor cost of each quarterly lot caused by the R&M design changes in the lot. The design changes were hypothesized to cause a certain percentage of the assembly procedures to change. The new procedures, represented by the third term of f_4, started out on point one of the labor learning curve. The old procedures, represented by the second term of f_4, were subtracted from the labor learning curve. For example, a one percent change at aircraft 300 would result in addition of three aircraft from points 1-700 and subtraction of three aircraft from points 301-1000. This learning curve shift was hypothesized both because it seemed probable and because it explained the sawtooth cost curve phenomenon detected, among other analysts, by Scott [9].

The labor cost changes for each period thus were based on all labor subcosts from the f_2 equations for that and all later periods.

The changes in assembly procedures for each period were postulated to be proportional to the increased reliability for the period. Therefore, each airframe and avionic subcost was multiplied by the u term for the previous period, and each propulsion system cost was multiplied by the v term for the previous period. Finally, all subcosts were multiplied by the Frager Coefficient, .1 .

The .1 estimate also was subject to uncertainty. Both Government records and company records were available, but neither had a tabulation of subcosts that could be used to relate reliability design changes to production labor. Engineering change proposals might be used, but they could only be used with some procedure, which would probably be a sampling procedure, for estimation of increased production times and the percentages of those times that could be charged to reliability design changes. The .1 estimate finally was made as the estimate most compatible with program cost records of NavAirSysCom and the Center for Naval Analyses. Because of the extreme uncertainty, the value was tripled in a series of sensitivity runs. These runs indicated no significant sensitivity to the tripled value, so the uncertainty of the estimate was left unresolved.

No retooling costs or costs of materials were included in f_4 as they were considered to be negligible.

The number of three-month periods in the TAF program, g, was a variable to be optimized, and was allowed to vary without restriction.

Operations and support. The cost of operation and support, f_5, was given by:

$$f_5 = \sum_{i=1}^{40} X_i \,[12.8976(w_{5,i} + w_{6,i}) + 10.778\,(w_{5,i+15} + w_{6,i+15})$$

$$+ 9.0069\,(w_{5,i+3} + w_{6,i+31}) + 7.5268\,(w_{5,i+47} + w_{6,i+47})]$$

where

$$w_{5,i} = k_{13}\, k_{16}\, F_a,\ i = 1 \text{ or } 2\ ,$$

$$w_{6,i} = k_{13}\, k_{16}\, F_p\ ,\quad i = 1 \text{ or } 2\ ,$$

$$w_{5,j} = k_{13}\, k_{16}\, F_a\ (1-c)\ (k_{13} w_{3,j-1})^{-c},\ 3 \leq j \leq\ g\ ,$$

$$w_{6,j} = k_{13}\, k_{16}\, F_p\ (1-c)\ (k_{13}\ v\ w_{3,j-1})^{-c}\ ,\ 3 \leq j\ \leq g\ ,$$

$$w_{5,i} = w_{5,g}\ ,\ i\ > g\ ,$$

$$w_{6,i} = w_{6,g}\ ,\ i\ > g$$

k_{16} = average cost of unscheduled maintenance action = \$300 (best case) to \$600 (worst case)

F_a = initial failures per flight hour, airframe plus avionics, first aircraft = 3

F_p = initial failures per flight hour, propulsion system, first aircraft, = 1 .

The k_{16} value was estimated at \$375 with a low estimate limit of \$300.00 and a high estimate limit of \$600.00. This cost range was considered representative of the aircraft of interest on the basis of VAMOSC records of high performance Navy fighter and attack aircraft. The initial failure rates similarly were selected as representative of the rates predicted for the aircraft of interest on the basis of a regression analysis of both high performance and low performance aircraft made by the Rail Company of Baltimore.

Modification. The modification cost, f_6, was estimated with

$$f_{6,j,k} = 21{,}000\ (k-j) + 300{,}000\ (U_k - U_j)$$

where

$f_{6,j,k}$ = cost of reliability changes, modification of one aircraft from period j design to period k design,

$$U_\ell = \sum_{i=1}^{\ell-1} u_i \ .$$

Thus, reliability modification of a propulsion plant cost \$21,000 for each period that separated the new design from the old one. Reliability modification of the airframe and avionics cost \$100,000 for each decrease of one in the number of failures per hour. Both of these estimates were based on NavAirSysCom records for 1975-1980 for high performance jet fighter aircraft.

Under the anticipated modernization program, all reliability and maintainability modifications were to be made during depot rework. Each aircraft was to have three depot reworks separated by fleet service periods of 3.5 years. Thus, the costs for one lot, f_{6j}, were given by

$$\begin{aligned} f_{6j} = {} & X_j\ a^{14}[21{,}000(I_{j+15} - I_j) + 300{,}000\ (V_{j+15} - V_j)] \\ & + X_j\ a^{28}[21{,}000(I_{j+31} - I_{j+15}) + 300{,}000\ (V_{j+31} - V_{j+15})] \\ & + X_j\ a^{42}[21{,}000(I_{j+47} - I_{j+31}) + 300{,}000\ (V_{j+47} - V_{j+31})] \end{aligned}$$

where

$$I_i = i \,,\; i \le g$$

$$I_i = g \,,\; i > g$$

$$V_i = U_i \,,\; i \le g$$

$$V_i = U_g \,,\; i > g$$

In this equation, a^n represented the percentage of the original lot left unattrited after n periods of use. The bracketed term, which represented the modification cost of one aircraft, had a value of zero when the aircraft entering rework already was of lot g design.

4. Search Algorithm

The recommended production schedule and TAF duration were found by a three-step process. First the subspace of vectors believed to contain the optimum production schedule vector was defined by a set of basis vectors. Then the optimum TAF duration was found for each basis vector. Finally, the best combination of optimum basis vectors was found.

This methodology was developed because the problem was not amenable to conventional techniques. A sequential unconstrained minimization technique was tried initially. Because the derivatives could not be determined analytically, however, the computer running time proved to be beyond reason. In addition, purely continuous techniques could not be employed because aircraft must be produced in integral numbers.

Branch-and-bound methodology therefore was selected. A conventional branch-and-bound enumeration, however, was precluded by the number of permutations. As a consequence, an iterative evaluation procedure was adopted.

Under this procedure, the production schedule that minimized each of the six subcosts was found. The schedules are shown in Figure 2, which also shows a "base case" schedule, A, that represents current practice and was included for comparison purposes. The schedules were regarded as basis vectors for the subspace containing the unknown optimum vector.

After the schedules had been determined, the optimum TAF phase duration was found for each schedule. This was accomplished by calculating the total program cost for durations varying from approximately four to approximately eight years. For each schedule, total cost was found to decrease monotonically with increasing TAF phase duration until a minimum point was reached. Then total cost increased monotonically.

In the final step, a succession of combinations of schedules C and D was evaluated. The results are given in the following section.

5. Results

Production schedule constraints. All production schedules were permitted without regard to national needs as long as four constraints were met: (1) at least 1000 aircraft had to be produced; (2) all 1000 had to be delivered within ten years; (3) at least a dozen prototype aircraft had to be fabricated, tested, and redesigned before the production phase of the program could be started; (4) at least 30 months lead time had to be given to the contractors. Military requirements were disregarded because the purpose was the minimization of life cycle cost under only manufacturing constraints; any conflict between cost minimization and military requirements could be resolved by trade-off analyses.

Optimum schedule. The optimum production schedule is shown in Figure 3, which covers the 30 quarter-year periods in the production phase of the program. The schedule has five principal characteristics:

(1) Production is spread over the entire time allowed; the economies of accelerated production do not offset the increased costs.

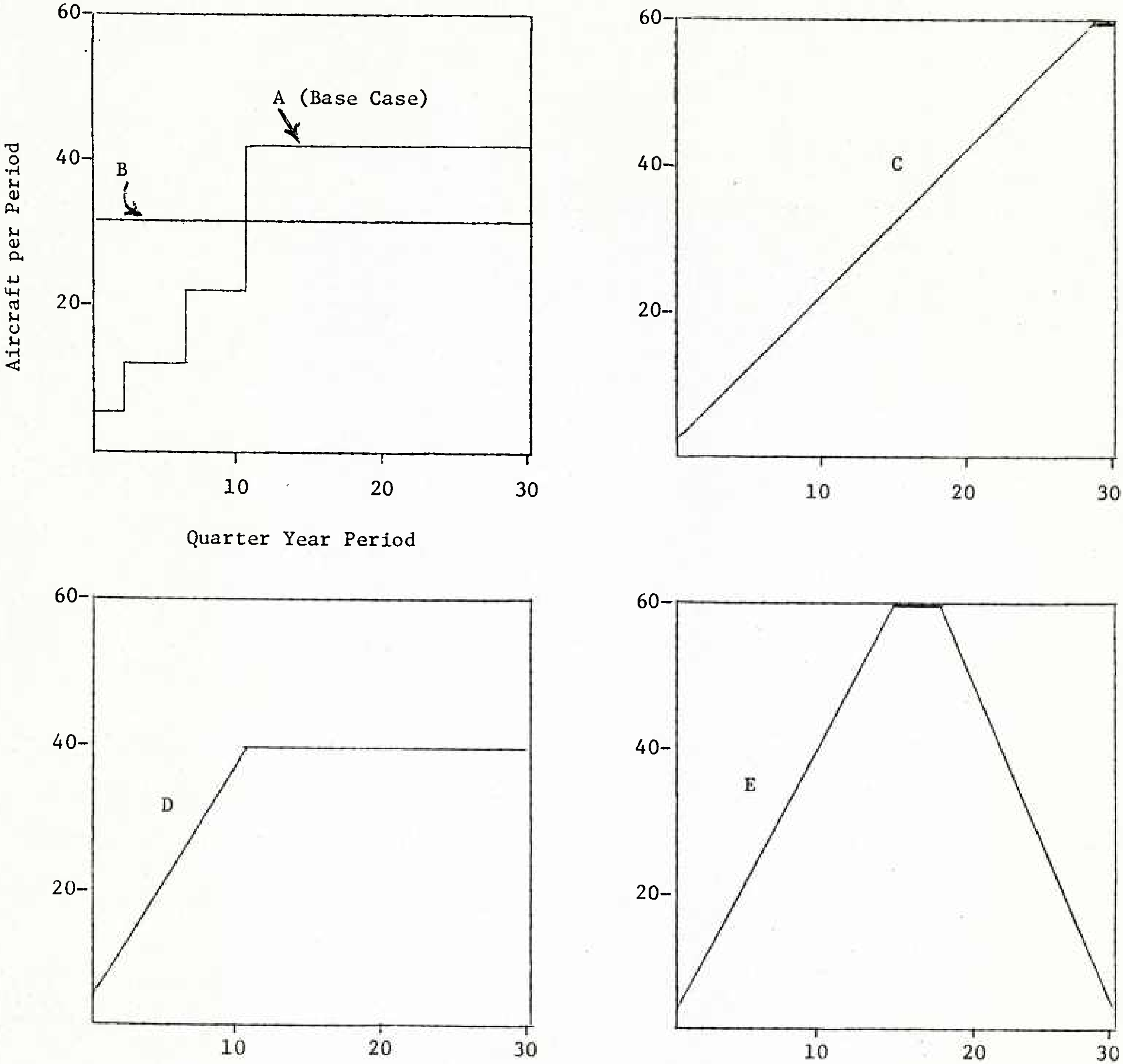

Figure 2. Alternative Production Schedules

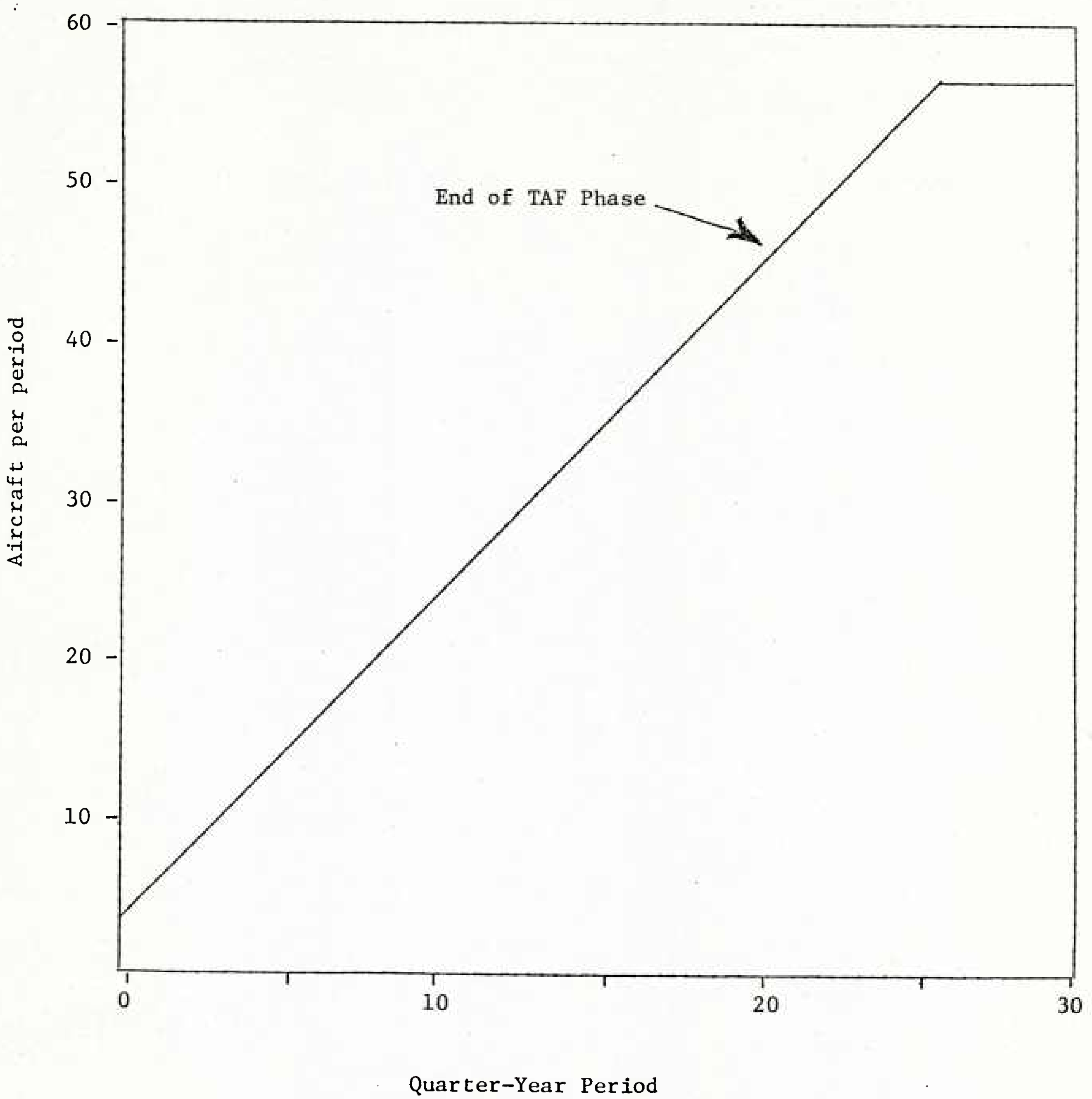

Figure 3. Minimum Cost Production Schedule

(2) Production build-up occurs linearly rather than in steps.

(3) Production build-up is extended approximately through the first 85 percent of the production period rather than the first three or four years.

(4) Production remains steady after completion of production build up.

(5) The Test, Analyze, and Fix phase is extended approximately through the first two-thirds of the production period rather than the first one-third or less.

The Figure 3 schedule had a cost per aircraft of $4,270,710, which was some 1.7 percent lower than a "base case" cost of $4,343,910. The base case schedule, which was selected to represent current practices, is shown among other schedules in Figure 2. The cost per aircraft of the base case schedule with the optimum TAF phase cut off point, which was the seventeenth quarter of the production phase, was $4,290,370, approximately 1.2 percent lower than the reference point cost. Values relative to total life cycle costs could not be estimated, of course, because total life cycle costs were not estimated. In addition, the dollar values were subject to so much uncertainty that they are considered to indicate only relative preferences rather than the magnitudes of those preferences.

Sensitivity. Three estimates were made of each critical variable, a best estimate and the two 95 percent confidence interval estimates. The estimates of the four most critical variables were then grouped into the five sets of conditions shown in Table 1:

(1) Liberal - all variables had values that would favor the proposed changes except the Frager Coefficient, which had the same value for both the lowest estimate and the best estimate.

(2) Mixed liberal - a liberal Duane Exponent was used with conservative values for the other variables.

Table 1

Sensitivity Analysis Cost Estimates

(Each entry shows the lowest cost for the schedule and the TAF phase duration that resulted in that cost.)

Schedule	Liberal Conditions		Mixed Liberal Conditions		Best Estimate Conditions		Mixed Conservative Conditions		Conservative Conditions	
A	5,874	34	5,351	29	4,290	27	4,085	26	4,598	21
C	5,861	36	5,301	30	4,271	29	4,063	27	4,515	21
D	6,782	30	5,757	23	4,646	24	4,378	24	4,716	18
E	5,937	32	5,542	27	4,367	25	4,168	24	4,867	20
F	5,860	36	5,300	30	4,270	29	4,062	27	4,514	21
Variable										
Duane Exponent	.1		.1		.2		.3		.3	
Annual TAF Cost	$500,000		$2,300,000		$1,300,000		$500,000		$2,300,000	
Frager Coefficient	.1		.3		.1		.1		.3	
Failure Cost	$600		$300		$375		$600		$300	

(3) Best estimate - all variables had their expected values.

(4) Mixed conservative - a conservative Duane exponent was used with liberal values for the other variables.

(5) Conservative - all variables had values that would minimize the advantages of the proposed changes.

The order of preference was the same in all five cases - F, C, A, D, E. The best production schedule that is compatible with aircraft delivery requirements therefore evidently can be selected in advance without predictions of the four critical variables.

Schedule B, incidentally, was dropped from consideration after the first few computer runs showed that it would result in very high costs under all conditions. The schedule was included originally without regard to the practical difficulties of an immediate transition from prototype to full-scale production because the production schedule vector was a basis vector of the subspace containing the optimum vector.

The selection of the TAF phase duration, unlike the selection of the production schedule, requires advance indications of the values of the four critical variables. The optimum termination time ranged from 40 percent to 80 percent of the production phase. Slow reliability growth resulted in a longer time to reach the point at which further improvements cost more than they saved. The best time to make a final decision on the duration apparently would be after the first three or four years, when the critical variables would be fairly well established.

6. Conclusions

. Before the production contract is awarded for a first generation aircraft, life cycle cost and reliability analyses should be made of the range of production schedules compatible with aircraft delivery requirements and anticipated production constraints. The schedule selected should be the one with the lowest life cycle cost as predicted from expected reliability growth.

- If uncertainty precludes reliability and cost analyses, the production build up termination date should be the latest one compatible with delivery requirements. Build up should be linear.

- Predictions of critical reliability improvement characteristics should be made within the first three or four years of a first generation aircraft program. The Test, Analyze, and Fix program should then be planned accordingly. In a program such as the one considered here, the TAF phase should have a duration of five to ten years depending primarily upon the exponent of the reliability improvement curve.

- Adoption of these recommendations might reduce costs by from $50,000 to $350,000 per aircraft for a statistically typical aircraft of the type studied.

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Naval Ship Res & Dev Center

Naval Sea Systems Command
PMS 30611
Tech Library
Code 073

Naval Supply Systems Command
Library
Operations and Inventory Analysis

Naval War College Library
Newport

BUPERS Tech Library

FMSO

USN Ammo Depot Earle

USN Postgrad School Monterey
Library
Dr Jack R. Borsting
Prof C. R. Jones

US Coast Guard Academy
Capt Jimmie D. Woods

US Marine Corps
Commandant
Deputy Chief of Staff, R&D

Marine Corps School Quantico
Landing Force Dev Ctr
Logistics Officer

Armed Forces Industrial College

Armed Forces Staff College

Army War College Library
Carlisle Barracks

Army Cmd & Gen Staff College

Army Logistics Mgt Center
Fort Lee

Commanding Officer, USALDSRA
New Cumberland Army Depot

Army Inventory Res Ofc
Philadelphia

Army Trans Material Cmd
TCMAC-ASDT

Air Force Headquarters
AFADS-3
LEXY
SAF/ALG

Griffiss Air Force Base
Reliability Analysis Center

Gunter Air Force Base
AFLMC/XR

Maxwell Air Force Base Library

Wright-Patterson Air Force Base
AFLC/OA
Research Sch Log
AFALD/XR

Defense Technical Info Center

National Academy of Sciences
Maritime Transportation Res Bd Lib

National Bureau of Standards
Dr B. H. Colvin
Dr Joan Rosenblatt

National Science Foundation

National Security Agency

Weapons Systems Evaluation Group

British Navy Staff

National Defense Hdqtrs, Ottawa
Logistics, OR Analysis Estab

American Power Jet Co
George Chernowitz

General Dynamics, Pomona

General Research Corp
Library

Logistics Management Institute
Dr Murray A. Geisler

Rand Corporation
Library
Mr William P. Hutzler

Carnegie-Mellon University
Dean H. A. Simon
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Prof R. W. Conway
Prof Andrew Schultz, Jr.

Cowles Foundation for Research
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Florida State University
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Prof W. G. Cochran
Prof Arthur Schleifer, Jr.

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Prof A. W. Tucker
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